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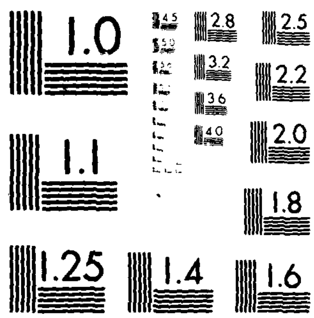

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SHIP-II SIMULATION MODEL: VALIDATION AND EVALUATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The SHIP-II computer simulation model, developed to assess the adequacy of manning suites for Navy ships, has been extensively revised since its initial development (1962). Prior to this effort/report, no systematic verification and validation of the model has been conducted and documented. This report describes the results of these tasks. It was determined that the SHIP-II model is not an accurate tool for the examination of manpower requirements and manning policies for Navy ships.

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FOREWORD

This research and development was conducted in support of task area ZF57.525.001.023.03.02 (Mathematical Models of Manning Utilization). The overall objective of this task area was to develop and demonstrate improved methodologies for assessing variations in manpower utilization on the operational performance of Navy platforms.

This report documents the capabilities and shortfalls of the SHIP-II model, which was developed to assess the adequacy of manning suites for Navy ships. It was determined that further development of SHIP-II is not warranted because of cost considerations and the difficulties involved in simulating shipboard operations as they affect manpower utilization and scheduling. Since this report describes some of these difficulties, it should be useful for future research on similar undertakings.

Acknowledgements are due to S. E. Bowser, E. R. N. Robinson, R. N. Harris, and P. Billingsley of the Navy Personnel Research and Development Center for their early contributions to the documentation of the original SHIP-II model. Acknowledgements are also due to the project personnel of B-K Dynamics, San Diego, California, who performed much of the analysis of SHIP-II.

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SUMMARY

Problem

The SHIP-II computer simulation model was developed to assess the adequacy of manning suites for Navy ships. The model has been extensively revised since its initial development in 1962, but no extensive verification or validation of the model had been conducted.

Objectives

The objectives of this effort were to verify and validate the SHIP-II model and determine its utility for assessing manpower requirements for Navy ships.

Approach

The computer program was verified by a careful examination of the program logic to ensure that it does what it was intended to do. A baseline stability analysis and a sensitivity analysis were also conducted to determine model response to changes in the input variables. Model validation was conducted by critically examining the underlying model assumptions to determine if they might cause the model to diverge from reality. An effort was made to compare actual man-hour data gathered from USS ARTHUR W. RADFORD (DD 968) with results of a SHIP-II simulation of this ship, using as the scenario the actual operation scenario experienced by RADFORD during the time period that man-hour data was collected. An exercise was also conducted to compare the results of changing the manning suite for a typical DD 963. Two manning suites were used--manning taken from the Ship Manning Document (SMD) and manning from the Navy Manning Plan (NMP). A post-processor was built to facilitate the statistical analysis of the outputs from a simulation run.

Findings and Discussion

1. The SHIP-II model verification analysis and manning-suite change exercise show that the existing computer logic and programs do not accurately model the desired ship, equipment, and manpower interactions. Many logic deficiencies and omissions detract from its fidelity.

2. The baseline stability analysis and sensitivity analysis show that the model exhibits the desired stability over time and the expected response to changes in the input variables. However, the degree of this response could not be measured due to lack of: (a) enough data to make a statistical statement about the changes (due to excessive computer costs required to generate the data) and (b) confidence in the fidelity of the model.

3. While the results of the comparison of model output and actual data are generally favorable, the results of the model validation experiment must be considered inconclusive due to the limitations of the actual data collected.

4. The use of the model is limited because data input requirements are excessively high. For example, to exercise one ship in the model requires approximately 3 man-months to acquire and assemble data not in a machine-readable format.

Conclusions

The SHIP-II simulation model is not an adequate tool for examining manpower requirements and manning policies for Navy ships. It is, however, the only model that encompasses all ship evolutions and an operational scenario. There are several logic deficiencies and omissions that must be rectified to ensure fidelity of the model. These required changes, together with excessive and complex data requirements, preclude the use of SHIP-II by Navy operational managers.

Recommendation

Because of cost considerations and the technical difficulties involved in developing a useful ship simulation model, further efforts should not be made to modify and further develop SHIP-II at this time.

CONTENTS

LIST OF TABLES

INTRODUCTION

Problem

The SHIP-II model was developed to provide a simulation of a Navy ship for the purpose of studying the interaction of manpower, ship's equipment, ship's operational employment, and personnel and management policies and constraints. While there is a need in the Navy for manpower analysis techniques such as the SHIP-II model, their technical adequacy must be carefully examined. A computer simulation is only as sound as the techniques and data used in constructing it. Prior to its use, a simulation model must be validated, or shown to actually model the system being studied. Research applications of computer simulation models and the decisions based on such applications have often preceded objective evaluations of the models involved. Although several small-scale special-purpose studies conducted at various stages of the model's development have tended to confirm the validity of SHIP-II, it has never been subjected to a full-scale verification and validation effort.

Objectives

The objectives of this effort were to verify and validate the SHIP-II model and determine its utility for assessing manpower requirements for Navy ships.

Background

SHIP-II is designed to simulate normal activities conducted aboard a Navy ship. The simulation model is used to determine the impact of various operational and workload factors on personnel resources. SHIP-II is an event-oriented, digital model that uses the Monte Carlo method to produce random samples of events from empirically-derived frequency distributions. Events include the assignment of personnel to watches, performance of maintenance and work, equipment failures, training exercises and classes, and other normal activities and occurrences on a Navy ship. The model is driven by a scenario that lists initiation times and durations for operational events such as training exercises, changes in readiness conditions, and evolutions.

SHIP-II was developed as a follow-on to the DDG 2 Total Ship Simulation Model. Since 1970, the SHIP-II model has undergone several major revisions. Most revisions are due to attempts to apply the model to a variety of manpower and personnel research problems. The result is a large-scale computer simulation model of a destroyer-class ship. This analysis concentrated on the verification and validation of the SHIP-II model in its present form.

APPROACH

A simulation model is validated by demonstrating that it is an accurate representation of the real system it is designed to simulate. Validation should not be confused with verification. Verification of a computer program is an examination of the program logic and output to ensure that it does what it was intended to do. A verified computer program can, in fact, represent an invalid model. That is, the program logic may accomplish exactly what the programmer intended without representing the operation of the real system.

Validation of computer simulation models is a difficult task and there is little agreement about what constitutes adequate validation. Despite this lack of agreement,

there are techniques that have proven useful in model validation.[1] One technique is to compare the results of the simulation with results historically produced by the real system operating under the same conditions. A second technique is to use the simulator to predict results that can then be compared with the results produced by the real system during some future period of time. Hidden, but nonetheless critical, assumptions may cause the model to diverge from reality. One purpose of the model validation process is to discover such assumptions. They are best detected by a diligent examination of the model's underlying assumptions and design.

The analysis included in this effort consisted of: (1) a review of existing SHIP-II documentation (a rough draft of the user's guide)[2] and a careful examination of the computer code, (2) a sensitivity and stability analysis of the model's output parameters, (3) a comparison of actual man-hour data gathered from USS ARTHUR W. RADFORD (DD 968) with results of a SHIP-II simulation of this ship, and (4) a comparison of SHIP-II output for two distinct manning suites for a typical DD 963 class ship. The sensitivity and stability analyses revealed major flaws in the model. During this investigation, even thoug results indicated that stability and a degree of sensitivity exist in the output parameters, the output levels of several parameters appeared suspicious. This prompted careful examination of the computer code, which, in turn, led to the discovery of several flaws in the model's logic. Many other problems were encountered during the subsequent comparison of SHIP-II output for two distinct manning suites.

FINDINGS AND DISCUSSION

This description of the analysis performed on SHIP-II is divided into two major categories. The first area concerns the results of all efforts categorized as a verification analysis. These include (1) a careful examination of the actual computer code to determine how accurately the model reflects current Navy ship tasking practices, (2) a test for the stability of the model results by using different random number seeds to begin a simulation, and (3) an analysis to test the output variable sensitivities to changes in the input parameters and to determine the workload impact of varying the manning levels and skills provided as the ship's crew.

The second type of analysis (usually called validation) consisted of two major efforts. First, in conjunction with the verification, several special runs of the model were made utilizing output commands to determine the fidelity of the model's watch and maintenance assignments and to check that man-hours are accumulated in each activity correctly (a face validity test). Finally, an attempt was made to compare results of a SHIP-II simulation of RADFORD with man-hour data that was collected by project personnel while aboard the same ship.

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[1]For an exposition of this problem, see Schechter, M. and Luca, R. C. Validating a large-scale simulation model of wilderness recreational travel. Institute of Management Sciences, 1980, 10(5), 11.

[2]A copy of this guide may be obtained upon request from NAVPERSRANDCEN, Code 11.

Verification Analysis

Code Examination and a Face Validity Test

Face validity is evaluated in terms of the "reasonableness" of a simulation model's output. To this end, several runs of the SHIP-II model were made, over periods of 21 to 35 days (using an input data set developed for a typical DD 963). The model was instructed to give a snapshot of its transaction table and work assignments every 4 hours of simulation time. Concurrent scrutiny of the output and its associated input, as well as careful examination of the underlying computer code comprising the various subroutines of SHIP-II, revealed a number of model logic deficiencies and omissions that detract from the fidelity of SHIP-II. The problems encountered are discussed below.

No Fair-Sharing of Workload. The earlier documentation of division training states that individuals are assigned to a class from the top of the division manning list downward until the class is filled. Because of this, individuals near the bottom of the list might not accumulate as many division training hours as would those nearer the top of the list. The same logic is used in the assignments to critical maintenance and other work. Consequently, the work is not fair-shared, which usually results in a wide disparity of the average weekly workloads for men in the same division. The men near the top of the division list tend to have workloads that exceed the Navy standard workweek, while those near the bottom tend to have workloads that fall short of a standard workweek. In some cases, the difference is as much as 50 man-hours/week.

The SHIP-II program contains a subroutine, LAZFST, which sorts a list of man-numbers by hours worked and puts the man with the least hours of work at the top of the list before scheduling work. However, this subroutine is only called from two places in the program. In both instances, the jobs being scheduled are administrative support. There is no apparent reason why it is not used for other work scheduling.

The following example illustrates this non-fair-sharing of work. Table 1 shows the work assignments of a GSM3 NEC 4111 (man No. 11 in the MP Division) over a 4-day period. Table 2 shows the number of hours three identical men in the MP Division worked during the same 4-day period.

Each man is a GSM3 NEC 4111 and each stands watch. The difference in the total man-hours worked by the four men is caused by the repeated corrective maintenance (CM) requirements placed on the first man. When total workload for this rate and/or NEC (Navy enlisted classification) code is examined, this may not be a problem because averages over the total ouput are used. However, there may be a distortion in the man-hours worked by a particular NEC when the model assigns work by rate only when there is more than one NEC.

Incomplete Transaction not Appearing in the Output. In the previous example, an individual apparently worked 25 hours in a 24-hour day because of a transaction that began on one day and did not end until the following day. All hours spent on this transaction are attributed to the second 24-hour day. In practice, the errors are small. Nonetheless, a user should be aware that minor errors might occur from week to week.

Inaccurate Preventive Maintenance (PM) Scheduling. Based on a statistical analysis of the data generated from five different runs of SHIP-II with different random number seeds (this will be further discussed later in this report), the hypothesis that there is no increase or decrease in PM man-hours over time must be rejected. Each of the five baseline runs showed a statistically significant increasing trend in PM man-hours over the

Table 1

Assignment of Man No. 11 Over 4-day Period

Time	Monday	Tuesday	Wednesday	Thursday	Total (Hrs)
0100	Watch	Watch	CM	Watch	
0500	Idle	CM	Watch	CM	
0900	PM	CM	CM	CM	
1300	Watch	Watch	CM	Watch	
1700	Watch	Watch	Watch	Idle	
2100	CM	CM	CM	Watch	
Total (Hrs)	19.72	19.00	25.46[a]	19.00	83.18
Average					20.80

Note. CM is corrective maintenance and PM, preventive maintenance.

[a]The accumulated total is greater than 24.0 hours because, when a maintenance action is continued past 2400 on one day, the accumulated task-hours are added to the following day.

Table 2

Assignment of Men Nos. 12-14 Over 4-day Period

	Hours Per Day				
Man	Monday	Tuesday	Wednesday	Thursday	Total
12	14.75	19.89	19.00	23.86	77.50
13	14.75	17.50	17.49	16.50	66.24
14	10.50	18.75	22.28	13.75	65.28

13-week scenario. The reason for this trend is believed to be in the way the model simulates the performance of PM. The model's treatment of PM appears to be both inaccurate and unrealistic. The causes can be attributed to both the PM input data and the program logic. Some specific faults with the PM logic are:

1. The PM workload (measured in man-hours) increases over time, because of (a) the steady buildup from week to week of unaccomplished PM carried over to the next week and (b) the scheduling of semi-annual, annual, and cyclic PM tasks late in the scenario.

2. When a PM check cannot be conducted because of other actions (higher priority work, equipment failure, etc.), the model attempts to reschedule the check every 45 minutes. This is an inefficient, possibly excessive, use of computer time to accomplish

PM. The frequency of rescheduling attempts is not in consonance with common Navy practice.

The net effects of these faults are important to the operation of the model. The model, which presents an unrealistically pessimistic view of the PM workload, has a reasonable scheme for scheduling part of the PM. Daily and weekly checks are scheduled every day and on the first day of the week, respectively. The monthly, quarterly, semi-annual, annual, and cyclic checks are evenly distributed within each period. For example, if 16 monthly checks are on the list, four are scheduled each week of the month. However, the semi-annual, annual, and cyclic checks do not begin to appear on the schedule until the latter portion of the run. Once the model begins to run, any interruptions or delays in scheduled PM (and there are many) cause the PM workload to begin a steady growth as the PM tasks are rescheduled in the following days and weeks.

There are four changes that could be made to improve the PM logic:

1. Extend the at-sea PM workday from the current 0800 to 1630 to 0800 to 2200.

2. Rather than attempting to schedule PM at the beginning of each day and rescheduling every 45 minutes, schedule PM following watch assignments and changes in readiness conditions from Condition I or II to Condition III or IV.

3. Allow PM to be performed on watch.

4. Give PM a higher priority relative to other workload factors.

Deferrals for Assistance. Deferrals for assistance are made when the repair of the existing casualty requires the material resources of a repair facility or the assistance of specially trained and experienced maintenance specialists, who are normally in scarce supply and stationed ashore. This outside repair assistance is generally not available until the ship next enters port. In the current model, the deferral for assistance is executed at the time the decision is made to defer and remains in effect for some time specified in the input data set. It would be more realistic to simulate the decision to defer, as is currently done, and then delay the completion of this deferred maintenance action until the next in-port period. The affected item of equipment would remain out of service for the remainder of the current at-sea period and for the expected repair time period after reaching port.

Watchstanding Policy. As a general rule, a man on watch would remain on watch until a suitable relief is provided. If the normal relief is not available due to other commitments, then the watchstander should remain at his watch beyond his normal hours. In the current model, if the normal relief is not available and a substitute cannot be bumped from other requirements, the model will terminate. Contemporary Navy practice would have the current watchstander remain at his post until a suitable relief can be located and assigned.

Evolutions versus Equipment Readiness. As a general rule, even the most important evolutions would be postponed, or cancelled, if certain subsystems or equipment were inoperable. For example, a ship would not perform an underway replenishment alongside if any part of the steering system were out of service. No attempt would be made to anchor if the anchor windlass were defective. While the model checks for necessary subsystem and equipment readiness before attempting to perform training exercises, it does not follow this practice for evolutions. There were cases, for example, where the model was underway and performing evolutions with the main propulsion system out of

service and rated Condition IV. Before attempting to perform a training exercise, the model first checks the status of each subsystem and equipment critical to the exercise. If they are not in an acceptable state of readiness, the exercise is not conducted. This concept should be applied to evolutions.

Repair Team Size. Whenever a team is required to perform a maintenance action, the model limits the team size to four men. This has apparently not been a limiting factor in the ships tested thus far in SHIP-II. However, some ships (particularly replenishment ships) require large teams to perform some routine PM. Also, some new PM concepts such as total ship test plan require large teams for routine PM. Additionally, the model's team requirement for maintenance is too rigid. If a team cannot be assembled, the model cancels or delays the work. In Navy practice, this would not happen.

In-port Duty Section Assignments. The in-port work schedule and workload of a ship's crew are greatly affected by the number of in-port duty sections. The current Navy goal is to place crews in six in-port duty sections. However, the model provides for only four in-port sections and only one watch assignment per section. Moreover, the number of duty sections for watch are all fixed for each simulation run. They should, if realistic, be allowed to vary, depending on the operational scenario.

Number of Maintenance Tasks. The number of PM, facilities maintenance (FM), and administrative support (S/A) tasks is limited by the model's size. As a result, the original SHIP-II designers increased the magnitude of each individual task in an attempt to enter the entire tasking workload. Consequently, some tasks are not performed because they require too large a block of time.

"As required" PM. A concept analogous to the previous discussion of the relationship between equipment readiness and evolutions is the "as required" PM. In a typical ship, 20 to 30 percent of the PM requirements are not linked to any specific periodicity; rather, they are performed when certain situations arise. For example, a number of PM checks are performed on the guns and ammunition handling equipment prior to a gun-shoot. If the checks are not satisfactory, the shoot is not conducted. As the model does not consider this type of PM, it understates the actual PM man-hours required. This problem, along with several of the problems discussed above, force the nonwatchstanding workload to be much lower than would be realistically expected.

Bumping Logic. The model's bumping logic for job priorities (see Appendix A) is basically correct for the long run. However, it is fixed throughout the simulation run and should be allowed to vary based on the operational scenario.

Nonwatchstanding tasks. Another problem concerns the modeling of nonwatchstanding tasks. The model does have an "up" option on a task allowing the user to specify that a job should be performed by a specific rating-rate. However, if this man is busy, it will "up" to the next rate above and assign this man the task if he is not busy, and so on, up to, at most, 3 "ups." This is realistic, but the model is not sensitive to different repair times experienced by more senior personnel in each rating. There is probably a significant difference here.

Readiness. The model scores readiness, based on the material readiness portion of the Navy force operational readiness statistics (NAVFORSTAT)-defined readiness decisions. It does not consider supply, training, or skilled personnel constraints. as does the new UNITREP system. This leads to an overly optimistic score of ship readiness.

Troubleshooting Time. The time spent troubleshooting a failure has been eliminated from the model. Although the Navy's 3-M Maintenance Data System (MDS) collects man-hour data on corrective maintenance (CM), it does not distinguish mean time in function troubleshooting (MTTS). Moreover, the probability that troubleshooting is required is reported on the casualty reports (CASREPs) only for mission-critical equipments. Thus, the troubleshooting feature of the model has been eliminated. However, experience as well as expert testimony has revealed that a great deal of time is spent in this maintenance category. Again, SHIP-II does not account for some of the nonwatchstanding workload.

Model Data Requirements. A number of the model's input data requirements appear to have been formulated based on information that was to have been available in the Navy's 3-M MDS when the model was originally developed. In its initial development, the 3-M MDS was to have collected extensive data about shipboard PM and CM. However, after an adverse reaction from the fleet, the maintenance data collection requirements were reduced significantly. Today, the 3-M MDS does not collect any data on PM activities. The only available data on PM man-hours are the engineered standards listed on the PM requirement cards (PMCs). The MDS collects data on only a small portion of the total CM activities and, of that, only the total current maintenance man-hours are useful. No troubleshoot time is available. Current SHIP-II data requirements cannot be met because of these changes in maintenance data collection.

Stability of Model

Five baseline stability runs were made to test the degree of consistency in the model. Each run used the DD 963 class input data base, a 13-week scenario, and a different random number seed. The details of this analysis are discussed in Appendix B.

The results of the analysis among runs using different random number seeds support the hypothesis that changing the random number seed in otherwise identical runs of the model does not change the underlying population parameters. There were no statistically significant differences among the outputs of SHIP-II runs employing different random number seeds. All the runs appear to be random samples taken from the same population.

In an effort to detect trends in the model output over time, the means and variances of each variable were computed over all runs. Simple linear regression was performed on these values to discern possible trends. The mathematical details are also found in Appendix B. Trend analysis results showed some variation in the model output over time in some cases. In particular, it was found that PM increased over time in all cases. This problem as well as its resolution were mentioned earlier in the results of the verification analysis.

Sensitivity Analysis

The sensitivity of the model to changes in independent or input variables was tested with repeated simulation runs. In each run, all input variables, except one, were held at baseline levels. The exception in each run was a specific change in one of the input variables listed below:

1. Mean time between failures (MTBF).
2. Mean time in function repair (MTFR).
3. Mean time in function PM (MTFPM).
4. Probability of deferrals for assistance.
5. Mean time of deferrals for assistance.

6. Probability of deferrals for parts.
7. Mean time of deferrals for parts.

The mean and variance of each output variable of interest were computed and used to test the hypothesis that the sample mean value resulting from a sensitivity run was equal to the baseline mean value of that variable. The model is sensitive to changes in the input variables when this hypothesis can be rejected. The output data and statistical computations of the sensitivity analysis runs are displayed in Appendix B.

The results of the sensitivity analysis runs, while generally favorable, were not as definitive as the baseline stability runs. In general, the model reacts to changes in input parameters in expected ways. For example, a decrease in equipment MTBF causes an expected increase in man-hours expended in CM. The limited number of sensitivity analysis runs for each variable does not provide a large enough sample to permit predicting the range of output values resulting from specific changes to an input variable. The specific results achieved with changing some of the above input parameters are described below.

1. Mean Time Between Failures (MTBF). Four runs of the model were made using random number seed 177. In the four runs, the parameter variation ratio (PVR) for MTBF was set to make changes in MTBF of -90, -70, -50, and -10 percent. Statistically significant changes in CM man-hours and total man-hours were seen in response to the -50, -70, and -90 percent changes. Without extensive additional runs of the model, it is not possible to determine the exact relationship between variations in MTBF and CM man-hours. For example, using seed 177, when MTBF was reduced to 10 percent of its baseline value, the model generated 5 times as many failures for the main propulsion gas turbines and 6.28 times as many CM man-hours overall. Neither of these values are predictable from analysis of existing data.

2. Mean Time in Function Repair (MTFR). Three model runs were made to test sensitivity of changes in time in function for equipment repair. Again, random number seed 177 was used. The PVR for MTFR was set to make changes of +90, +50, and +30 percent and the resultant changes in CM man-hours were recorded and analyzed. As with MTBF, the changes were in the expected directions.

3. Mean Time in Function PM (MTFPM). Three runs of the model were made, using random number seed 177, to test the sensitivity of changes in MTFPM. The PVR for MTFPM was set to increase the input variable MTFPM by +90, +50, and +30 percent, and the resultant changes in PM man-hours were recorded and analyzed. As in the case of variations in MTBF, increases in MTFPM caused the expected corresponding increases in PM man-hours.

4. Deferrals for Parts and Assistance (Covers 5 and 7 above). Runs of the model were made to test sensitivity to changes in input parameters controlling deferrals. Changes in deferral for parts probability, mean, and standard deviation were made (10%, 0.01 hr, and 0.01 hr were changed to 25%, 120 hrs, and 48 hrs, respectively). Results were similar to those seen in changes to MTBF, MTFPM, and MTFR. That is, the parameter changes caused expected changes in output but of unpredictable amounts. The number of deferrals and the average time per deferral both increased.

The sensitivity of the model's readiness ranking system was tested in conjunction with changes in the MTFR parameter. When MTFR was increased by 90 percent, the output readiness states were analyzed to determine if longer repair time would cause a reduction in the average time spent in readiness condition CI and an increase in time spent at lower

conditions of readiness (CII--CIV). Table 3 shows the results of this test. The expected results were realized. A comparison study was made of the percentage of total scenario time spent in readiness condition CI versus the time spent in conditions CII--CIV on the baseline run and on the run where MTFR was increased by +90 percent. The analysis indicated a definite shift toward the lower readiness conditions when MTFR was increased. However, as experienced in all previous analyses, the specific degree of change could not be predicted from the available data.

Table 3

Readiness Summary

Week	Baseline		MTFR Increased by 90%	
	Time at CI (%)	Time at CII, III, IV (%)	Time at CI (%)	Time at CII, III, IV (%)
1	95.6	4.4	69.6	30.4
2	78.2	21.8	42.0	58.0
3	58.2	41.8	68.0	32.0
4	95.8	4.2	37.0	63.0
5	84.2	15.8	1.6	98.4
6	85.8	14.2	40.1	59.9
7	69.8	30.2	42.7	57.3
8	90.3	9.7	0.0	100.0
9	79.4	20.6	89.8	10.2
10	69.5	30.5	26.1	73.9
11	71.2	28.8	48.7	51.3
12	99.5	0.5	98.6	1.4
13	31.2	68.8	36.4	63.6
Average	77.6	22.4	46.2	53.8

Validation Analysis

Empirical Validation with DD 968 Data

Divisional time-card data reflecting the actual employment of ship's personnel in three divisions of RADFORD were collected by Navy personnel and provided for analysis and comparison with the output of SHIP-II. These data were collected over a 3-week period during the deployment of the ship in the Mediterranean. Personnel of the auxiliary (A), main propulsion (MP), and gunnery (G) divisions recorded their employment and the time spent in each task. The ship's logs were used to develop a 6-month employment scenario for use in the SHIP-II model that would reflect the actual employment of the ship during this period.

The ship was at sea in only 1 week during the data collection effort. The majority of in-port time was spent on holiday routine (half workdays) and maximum liberty for the crew. The SHIP-II model is not presently programmed to permit changes in the desired workweek during model runs. Given the limited data actually collected (3 weeks for the A and G divisions and 2 weeks for the MP Division) and the difference between the workweek of the model (standard Navy workweek) and the ship in-port (holiday routine), a

close comparison of model predictions and the actual historical data could not be accomplished. The results of the comparison must be considered inconclusive.

Navy Manning Plan/Ship Manning Document Alternative Manning Analysis

To determine the sensitivity of SHIP-II to alternative manning suites, two 52-week runs of the model were made by varying only the input data set by the manning suite. The first run used a manning suite extracted from the Ship Manning Document (SMD) for the DD 963. This document is prepared jointly by the Navy Manpower and Material Analysis Center, Atlantic (NAVMMACLANT) and the Navy Manpower and Material Analysis Center, Pacific (NAVMMACPAC) for each class of Navy ship in the fleet. It is based mostly on recorded data of work performed on the ships (i.e., it is ship-task generated and is not constrained by the number of bunks available on the ship or by the pool of manpower available to the Navy).

The second run of SHIP-II was made with the same set of input data, except for the manning suites. This time the manning suite was extracted from the Navy Manning Plan (NMP). This manning suite is constructed basically from the SMD after it has passed through the appropriate Navy channels for approval. During this process, personnel are removed from the original SMD to account for bunk constraints and to ensure a fair-sharing of the personnel pool. Appendix C illustrates the differences between the two manning suites defined for the DD 963.

Two realizations were made from this exercise. First, the work input for each category of labor (kept the same for each run and consisting of tasks defined by the SMD) was essentially accomplished by both manning suites. However, the NMP manning required heavier workloads from its personnel than the SMD did. Moreover, the number and length of scheduled and unscheduled maintenance queues (due to the lack of available qualified personnel) was greater for the NMP than the SMD. Second, SHIP-II also scores the ship's readiness (based solely on equipment availability). It was found that both manning suites produced roughly the same ship readiness score or, more specifically, the same overall mission critical equipment availability.

It may be concluded that the problems discussed earlier concerning the model logic and computer code have distorted the true maintenance and readiness picture. Otherwise, the nonwatchstanding tasks defined by the SMD are an understatement of the work that can be accomplished by this manning suite. Several selected weekly report summaries, which are displayed in Table 4, illustrate the differences in the results using the two manning suites. These weeks were selected depending on whether the ship was at sea or in-port during the entire week. Reports were selected at the beginning, middle, and end of the 52-week scenario. A few divisions under the NMP manning suite were severely overworked. The primary cause for the overworking can be attributed to the fact that SHIP-II did not prevent personnel who had already put in a full Navy workday from working.

The final observation made regarding the alternative manning exercise concerns the amenability of SHIP-II for performing this type of analysis. It is very difficult and time consuming to use SHIP-II for making alternative manning studies of a given ship class/type. If the researcher chooses to begin the analysis with a baseline manning suite and then alters the same baseline suite, the task is conceivable. However, if the researcher attempts to compare the results of two totally disjoint manning suites, the task approaches almost impracticability. This is attributable, primarily, to the input data requirements. If the two manning suites are very disjoint, as in the case of the NMP and SMD, the divisions are usually misaligned. This necessitates careful and tedious

Table 4

Selected Weekly Results of Alternative Manning Exercise

Week	Status	Ship Readiness % Time C1	Total Ship Workload (% Navy Workweek)		Equipment Failures			Preventive Maintenance Performance			Facilities Maintenance and Adminstrative Support Performance		
			Watch-stander	Nonwatch-stander	Total Down Time (Hrs)	Number of Failures	Total Queue Time (Hrs)	Avg Delay Rate (%)	Avg Cancel Rate (%)	Total Man-Hrs	Number Tasks Scheduled	Number Interrupts	Hrs Work Left
1	Sea	96.5	101	57	68.3	380	0	600	11.3	739.3	1341	200	696.0
		96.5	98	47	67.9	378	0	408	4.5	802.4	1352	168	518.0
7	Port	72.2	76	44	26.7	381	0	547	13.4	851.9	100[illegible]	64	619.2
		68.8	81	39	155.1	388	0	420	7.8	1190.5	1043	70	476.2
30	Sea	92.4	103	61	163.3	389	3.5	676	21.5	599.3	1655	651	930.3
		92.7	97	52	174.7	388	.3	387	13.8	689.0	1607	526	753.4
32	Port	92.4	77	45	37.2	372	0	587	12.0	877.9	1009	68	612.3
		100.0	81	38	37.2	372	0	322	4.1	953.7	1055	71	451.8
49	Port	92.4	75	45	54.6	390	0	526	11.8	1000.0	978	39	607.0
		100.0	80	38	82.6	393	0	282	3.4	1074.0	1033	50	457.9
52	Sea	78.6	108	64	77.2	386	0	560	16.7	616.0	1553	553	969.4
		70.0	104	55	117.7	392	0	327	16.7	616.0	1527	437	730.0

Note. All upper values are for NMP manning and lower values are for SMD manning.

reorganization of the input data set, particularly the watch station assignments, division definitions, and secondary NEC assignments. Consequently, a large number of input data cards must be changed. The current input data set for SHIP-II has many sections of data that are dependent on each other (i.e., a change made in one section results in many similar changes made in other sections). If all the resultant changes are not also made, SHIP-II will not complete processing but will terminate immediately.

Still another problem encountered in using SHIP-II concerns the computer time and output statistical analysis required. In order to perform any output data analysis correctly, it is necessary to make multiple runs of SHIP-II varying the random number seed. This is extremely expensive in terms of computer time and results in a large amount of data that a team of analysts must reduce in order to perform the statistical analysis. It should be noted that the results presented in Table 4 do not reflect this type of complete analysis; rather, they were generated by one run of SHIP-II with only one random number seed.

CONCLUSIONS

The SHIP-II simulation model is a deficient method for examining manpower requirements and manning policies for Navy ships. This report identifies certain logic deficiencies and omissions in the model that detract from its fidelity. Moreover, because of the many intricacies of the model's input and output and the general logistics of any analysis employing SHIP-II (such as the SMD/NMP manning suite analysis performed in this effort), a "quick-and-dirty" probe into a manning problem cannot be made with this model.

To make the model useful, it would be necessary to restructure the model's input. Currently, the SHIP-II input requirements are not only massive but extremely complex. The various model input sections are interdependent and yet have distinct and very different Navy data sources. Consequently, much effort is required to make the input sections consistent. All of this work must now be accomplished manually.

RECOMMENDATION

Because of cost considerations and the technical difficulties involved in developing a useful ship simulation model, further efforts should not be made to modify and develop the SHIP-II model at this time.

APPENDIX A

BUMPING LOGIC

BUMPING

The logic of bumping is based upon the following matrix, which is found in the IMITIL subroutine.

Current Status \ Possible Status	0	1	2	3	4	5	6	7	8	9	10	11
0	5	1	1	1	1	1	1	1	5	1	1	1
1	5	2	2	2	2	1	1	1	5	1	1	1
2	5	2	2	2	2	1	1	1	5	1	1	1
3	5	2	2	2	2	2	1	1	5	1	1	1
4	5	2	2	2	[illegible]	1	1	1	5	1	1	1
5	5	2	2	2	2	2	1	1	5	1	1	1
6	5	2	2	2	[illegible]	2	2	1	5	1	1	1
7	5	2	2	2	[illegible]	2	2	5	5	3	3	5
8	5	2	2	2	[illegible]	2	2	3	5	5	5	3
9	5	2	2	2	2	2	2	3	1	5	5	3
10	5	2	2	2	2	2	2	3	1	5	5	3
11	5	2	2	2	2	2	2	5	5	3	3	5

At each point in the simulation, every man has a status based on his job. The definition of each status number is:

0 Idle
1 Facilities Maintenance (FM)
2 Administrative Support (S/A)
3 Division Training
4 Preventive Maintenance (PM)
5 Corrective Maintenance (noncritical) (CM)
6 CM (critical)
7 Train Exercise
8 Watch (repair)
9 Watch (substitute)
10 Watch (regular)
11 Evolution

The rationale for the number codes in the matrix is explained in the following statements:

- Generally: a 5 gives an error; a 1 allows a bump; a 2 indicates no bump and no error; and a 3 allows a bump.
- Watch (10) bumps any column with a 1 or 3 in it. A 5 causes an error.
- When a repair team is being assembled for a job, a 1 in the column for the new job allows a bump.
- An evolution (11) will interrupt any job with a 1 or 3. A 5 causes an error.
- For a training exercise (7), a 5 causes an error, a 1 or 3 can be interrupted.
- When a substitute watch is being assembled, column 10 is examined for a 1.

Occasionally, a status comparison may be made in the program without going through the matrix. However, the checks observed in the test run seem to conform to the matrix.

The documentation of the current model states that critical equipment is maintained over all other jobs. However, that is false. Watch, training exercises, and evolutions are all more important than critical equipment repair.

APPENDIX B

VERIFICATION AND VALIDATION STATISTICS

VERIFICATION AND VALIDATION STATISTICS

Baseline Stability Analysis

Model reliability can be defined as the degree of consistency in the model; that is, the degree to which the same model, operating on the same inputs, will produce consistent outputs. In SHIP-II, random events are determined by a series of pseudorandom numbers drawn from a random number generator. These pseudorandom numbers meet certain criteria for randomness, but always begin with a certain initial value called the seed and proceed in a completely deterministic, repeatable fashion. SHIP-II simulation runs with a fixed input and the same random number seed will produce identical outputs. The choice of a different random number seed for SHIP-II will produce a different output. The first and most important objective of the baseline stability analysis is to determine if this apparent difference resulting from different random number seeds represents random samples drawn from the same population or some real difference in the model.

Once started, the SHIP-II model will simulate ship operations over a predetermined length of time, typically 13 to 26 weeks. Model consistency over time would require that the selected output variables such as watch hours, divisional training hours, corrective maintenance man-hours, and planned maintenance man-hours be independent of time.

If the model meets these tests of consistency, then the five baseline runs can be considered random samples drawn from the same population. The output data of these runs can then be used to estimate the population parameters for the output variables of interest.

Baseline Stability Tests

To test whether a change in the random number seed would result in statistically significant changes in the output variables for a fixed input, a single classification or one-way analysis of variance (ANOVA) was performed.

In this design, each run using a different random number seed can be considered to represent one and only one of five distinct populations with means $\mu 1$, $\mu 2, \ldots \mu 5$. We will test the hypothesis that all five means are equal.

For each output variable of interest, the 13 weekly values in a particular simulation run can be considered to be a random sample drawn from one of the five populations.

Analysis Procedure

The experimental design is:

Random number seed

	1	2	3	4	5		
	X_{11}	X_{21}	X_{31}	X_{41}	X_{5i}		
	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}		
	X_{13}	o	o	o	o		
	X_{14}	o	o	o	o		
	o	o	o	o	o		
	o	o	o	o	o		
	o	o	o	o	o		
	o	o	o	o	o		
	X_{113}				X_{513}		
Total	T_{1+}	T_{2+}	T_{3+}	T_{4+}	T_{5+}	T_{++}	Grand Total
Mean	X_1	X_2	X_3	X_4	X_5	X	Grand Mean

$T_{1+} = X_{11} + X_{12} + X_{13} + \cdots + X_{113}$

$T_{++} = T_{1+} + T_{2+} \cdots + T_{5+}$

$$X_i = \frac{T_{i+}}{n_i} = \frac{T_{it}}{13},$$

where n_i is the number of measurements in each population ($n = 13$ in this case).

$$\bar{X} = \frac{T_{++}}{N} = \frac{T_{++}}{65},$$

where $N = \sum_{i=1}^{5} M_i$.

The population variance σ^2 will be estimated in two ways and compared. A pooled estimate of σ^2 can be computed from

$$S_p^2 = \frac{\sum\sum X_{ij}^2 - \sum \frac{T_{i+}^2}{n_i}}{\sum n_i - K},$$

where K is the number of distinct categories or populations (K = 5 in this case).

The variance of the means can be computed from

$$S_m^2 = \frac{\sum \frac{T_{i+}^2}{n_i} - \frac{T_{++}^2}{N}}{K - 1}$$

We wish to reject the hypothesis of no difference in means, if the observed means are significantly more disperse than we would expect when all obtained from the same population.

The two quantities, S_p^2 and S_m^2, may be tested for significant difference by using the F ratio.

$$F_s = \frac{S_m^2}{S_p^2}$$

The hypothesis of equal means would be rejected when the F ratio, F_s, obtained exceeds the critical value of the F table for K-1 and

$\sum n_i$ - K degrees of freedom at the chosen level of significance.

An ANOVA table can be used to summarize the results of these computations.

	Sum of Squares	Degrees of Freedom	Mean Square
Means	$\sum \frac{T_{i+}^2}{n_i} - \frac{T_{++}^2}{N}$	K - 1	S_m^2
Within	$\sum\sum X_{ij}^2 - \sum \frac{T_{i+}^2}{n_i}$	N -K	S_p^2
Total	$\sum\sum Xij^2 - \sum \frac{T_{++}^2}{N}$	N - 1	

The hypothesis of no difference in categories (equal means) will be tested at the 5-percent level of significance and it will be accepted if the observed F value is less than $F_{.95}(4.60) = 2.53$.

Trend Analysis

Model consistency over time requires that the values of the output variables be independent of time. One criterion of independence is that the mean of this variable be the same for each increment of time.

In the case of trend analysis over time, this means that the mean of the dependent variable Y is the same for each increment of time X or that the slope of the trend line b = 0.

The equation of a trend line is

$$\hat{Y} = a + b X$$

where: $\hat{Y}$ is the estimated value of the dependent variable,
X is the independent variable time,
a is the Y intercept (the value of Y when X = 0), and
b is the slope of the trend line.

$$b = \frac{\sum xy - n \bar{X} \bar{Y}}{\sum x^2 - n \bar{X}^2}$$

$$a = \bar{Y} - b \bar{X}$$

$$\bar{X} = \frac{\sum X}{n} \qquad \bar{Y} = \frac{\sum Y}{n}$$

To test for independence, we will test the hypothesis that the slope b = 0. If this hypothesis cannot be rejected, we shall conclude that there is sufficient reason to believe, at the specified level of significance, that Y is independent of X.

The test statistic is

$$t_s = \frac{b}{S_e} \sqrt{\sum X^2 - n \bar{X}^2}$$

$$\text{where } S_e = \sqrt{\frac{\sum Y^2 - a \sum Y - b \sum xy}{n - 2}}$$

The hypothesis that b = 0, Y is independent of X, will be accepted if

$$-t_c < t_s < t_c$$

where $t_c = 2.201$ at the 5 percent level of significance and 11 degrees of freedom.

Analysis Results

The results of the baseline stability analysis for each of the variables of interest are presented on pages B-6 through B-20. Each page includes:

1. The output data for each random number seed with the mean and standard deviation shown for each run.

2. The ANOVA table used to test the hypothesis of equal means between runs for this variable.

3. The mean value of this variable of interest over all runs together with its standard deviation and the 95 percent confidence limits about the mean.

4. The results of the trend analysis performed for each run. The slope and intercept are displayed together with the coefficient of regression, r^2, and the test statistic, t_s.

PREVENTIVE MAINTENANCE MAN-HOURS

1.

SEED		129	157	177	199	999
WEEK	1	167.43	177.51	173.50	169.20	172.30
	2	136.63	134.97	143.23	142.63	138.25
	3	193.03	193.69	207.99	206.43	191.56
	4	172.11	161.32	171.86	176.18	167.33
	5	146.57	158.71	150.46	163.99	136.90
	6	159.61	162.18	163.57	162.24	173.75
	7	192.48	204.12	182.53	201.83	198.41
	8	253.40	253.01	243.25	240.24	247.11
	9	267.18	261.02	317.46	280.67	266.31
	10	190.52	203.91	192.90	187.41	182.22
	11	199.50	181.34	205.11	213.59	222.10
	12	268.33	279.44	279.33	279.29	278.06
	13	203.57	189.02	210.01	213.03	201.06
GROUP MEAN		196.18	195.94	203.17	202.83	182.72
S.D.		43.198	43.426	50.723	43.203	52.838

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	135361	1	
BETWEEN	3564.31	4	891.078
WITHIN	131796	60	2196.61

F-RATIO = .405661 < 2.53

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 199.44 mnhrs

S.D. 43.790 mnhrs

95% Conf limits $188.80 \leq \overline{X} \leq 210.09$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	7.10	6.40	7.50	7.25	7.53
INTERCEPT	145.51	152.13	150.68	152.06	145.39
r^2	0.41	0.33	0.33	0.43	0.43
ts	2.761	2.326	2.336	2.866	2.895

WATCH MANHOURS

1.

SEED		129	157	177	199	999
WEEK	1	13Ø4.33	18Ø7.2Ø	18Ø6.29	18Ø7.Ø5	1798.54
	2	1773.48	1771.64	1773.3Ø	1776.ØØ	1776.ØØ
	3	1237.34	1238.ØØ	123Ø.98	1235.85	1238.ØØ
	4	1953.88	1957.26	1955.96	1955.24	1958.4Ø
	5	1933.14	1934.Ø7	1933.64	1932.38	1936.28
	6	1Ø93.ØØ	1Ø94.ØØ	1Ø94.ØØ	1Ø94.ØØ	1Ø94.ØØ
	7	1674.94	1679.12	1677.39	1679.38	1672.13
	8	168Ø.ØØ	1675.18	168Ø.ØØ	1678.28	1677.93
	9	1757.2Ø	1776.ØØ	1773.Ø9	1776.ØØ	1776.ØØ
	10	1812.ØØ	1812.ØØ	1811.76	1798.19	181Ø.63
	11	14ØØ.ØØ	1398.24	1393.43	14ØØ.ØØ	1396.18
	12	945.ØØ	942.7Ø	945.ØØ	945.ØØ	945.ØØ
	13	1788.ØØ	1773.65	1783.98	1788.ØØ	1788.ØØ
GROUP MEAN		16Ø4.Ø2	16Ø4.54	16Ø4.45	16Ø5.Ø3	16Ø5.16
S.D.		326.916	327.765	328.5Ø2	327.358	328.Ø28

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	6.44394E+Ø6	64	
BETWEEN	156	4	39
WITHIN	6.44379E+Ø6	6Ø	1Ø7396

F-RATIO = 3.6314E-Ø4

DEGREES OF FREEDOM = 4 & 6Ø

3. BASELINE MEAN 1604.64 mnhrs
S.D. 317.3Ø4 mnhrs
95% Conf limits 1527.5Ø $\leq \bar{X} \leq$ 1681.78

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-2Ø.77	-21.29	-2Ø.88	-2Ø.95	-2Ø.69
INTERCEPT	1749.42	1753.61	175Ø.57	1751.66	1749.97
r^2	Ø.Ø6	Ø.Ø6	Ø.Ø5	Ø.Ø6	Ø.Ø5
ts	-Ø.847	-Ø.867	-Ø.847	-Ø.853	-Ø.849

CORRECTIVE MAINTENANCE MANHOURS

1.

SEED		129	157	177	199	999
WEEK	1	74.1Ø	27.72	3Ø.34	56.84	4Ø.35
	2	1Ø3.55	44.75	68.72	71.37	75.4Ø
	3	125.96	1Ø.48	131.9Ø	42.Ø6	56.47
	4	195.35	35.89	58.26	71.93	16.74
	5	26.Ø2	35.92	32.5Ø	13.78	29.46
	6	49.75	19.86	33.2Ø	12.3Ø	8.35
	7	44.99	93.43	67.98	15.17	115.73
	8	56.91	121.ØØ	29.69	63.Ø2	78.ØØ
	9	77.38	3Ø.8Ø	53.85	8.1Ø	123.Ø3
	10	3.93	39.32	83.99	117.14	33.29
	11	4.16	128.12	1Ø2.87	1ØØ.18	64.34
	12	14.73	29.9Ø	2.59	79.Ø5	3Ø.76
	13	16.3Ø	1Ø9.42	1Ø9.ØØ	21.69	61.32
GROUP MEAN		61.Ø1	55.89	61.91	51.74	56.4Ø
S.D.		55.355	41.218	37.28	35.999	35.274

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	105969	1	
BETWEEN	6Ø3.547	4	15Ø.887
WITHIN	1Ø5365	6Ø	1756.Ø9

F-RATIO = .Ø859222 < 2.5

DEGREES OF FREEDOM = 4 & 6Ø

3. BASELINE MEAN 57.39 mnhrs

S.D. 4Ø.546 mnhrs

95% Conf limits $47.54 \leq \bar{X} \leq 67.25$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-9.57	5.43	Ø.78	1.29	1.32
INTERCEPT	128.Ø3	17.9Ø	56.47	42.72	47.15
r^2	.45	Ø.26	Ø.Ø1	Ø.Ø2	Ø.Ø2
ts	-3.Ø22	1.981	Ø.27Ø	Ø.467	Ø.489

TOTAL MANHOURS

1.

SEED WEEK	129	157	177	199	999
1	2353.36	2822.23	2819.55	2842.88	2819.34
2	2863.79	28Ø5.44	2837.37	2839.84	2841.33
3	2421.73	231Ø.67	2453.23	2351.8Ø	2354.89
4	3173.8Ø	3Ø37.33	3Ø5Ø.Ø1	3Ø61.Ø3	3ØØ4.16
5	293Ø.5Ø	2953.32	2942.2Ø	2935.68	2928.78
6	2214.29	2146.7Ø	216Ø.48	2138.85	2147.26
7	2771.37	2836.Ø6	2789.51	2757.66	2847.85
8	2859.51	2912.94	282Ø.21	2867.38	287Ø.Ø1
9	291Ø.46	288Ø.34	2952.3Ø	2888.89	2993.51
10	2847.15	2897.3Ø	2932.59	2944.69	2866.86
11	2376.42	2496.39	2486.Ø4	2513.41	2461.87
12	2Ø77.89	211Ø.74	2Ø76.52	216Ø.77	21Ø3.19
13	2856.9Ø	2927.54	2993.92	2924.Ø7	2912.71
GROUP MEAN	27Ø4.4	27Ø2.16	2716.46	27Ø9.77	27Ø3.29
S.D.	323.249	322.5Ø9	319.36	311.372	32Ø.499

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	6.Ø7514E+Ø6	1	
BETWEEN	34Ø8	4	852
WITHIN	6.Ø7173E+Ø6	6Ø	1Ø1195

F-RATIO = 8.41935E-Ø3 < 2.53

DEGREES OF FREEDOM = 4 & 6Ø

3. BASELINE MEAN 27Ø7.35 mnhrs
S.D 3Ø9.168 mnhrs
95% Conf limits 2632.19 $\leq \bar{X} \leq$ 2782.51

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-24.53	-1Ø.69	-12.63	-1Ø.86	-12.43
INTERCEPT	2876.1Ø	2776.91	28Ø4.88	2785.76	279Ø.98
r^2	Ø.Ø9	Ø.Ø2	Ø.Ø2	Ø.Ø2	Ø.Ø2
ts	-1.Ø26	-Ø.431	-Ø.517	-Ø.455	-Ø.5Ø8

DIVISION TRAINING MANHOURS

1.

SEED		129	157	177	199	999
WEEK	1	20.50	20.50	20.50	19.50	20.50
	2	22.50	22.50	22.50	21.00	21.00
	3	19.50	20.50	37.43	19.00	20.00
	4	28.00	29.00	28.50	20.50	30.50
	5	20.50	20.50	20.50	20.50	21.50
	6	31.00	19.50	18.50	19.50	20.00
	7	18.50	18.50	18.50	19.50	19.00
	8	20.50	18.50	19.50	38.40	18.50
	9	29.50	31.00	20.50	30.00	19.50
	10	18.50	20.50	18.00	19.50	18.50
	11	18.50	29.50	29.00	40.87	19.50
	12	19.00	19.00	19.00	26.50	18.00
	13	22.00	19.00	29.50	29.08	19.50
GROUP MEAN		22.19	22.19	23.23	24.91	20.46
S.D.		4.395	4.507	5.978	7.576	3.178

SUMMARY TABLE
ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	1852.6	64	
BETWEEN	138.282	4	34.5706
WITHIN	1714.32	60	28.5719

F-RATIO = 1.20995

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 22.60 mnhrs

S.D 5.380 mnhrs

95% Conf limits $21.29 \leq \bar{X} \leq 23.90$

TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-0.13	0.22	-0.15	1.14	-0.35
INTERCEPT	23.48	22.04	24.29	16.94	22.94
r^2	0.03	0.00	0.01	0.34	0.19
ts	-0.548	0.063	0.331	2.397	-1.599

SUPPORT/ADMINISTRATIVE MANHOURS

1.

SEED		129	157	177	199	999
WEEK	1	187.13	187.97	187.79	187.64	188.ØØ
	2	191.81	191.81	191.81	191.81	191.81
	3	2Ø5.68	2Ø5.68	2Ø5.68	2Ø5.68	2Ø5.68
	4	183.1Ø	183.98	187.57	183.78	183.78
	5	185.2Ø	185.5Ø	185.51	185.51	185.21
	6	214.89	215.29	215.29	215.29	215.29
	7	2Ø4.24	2Ø4.27	2Ø4.27	2Ø3.47	2Ø4[illegible]
	8	217.22	216.92	217.32	216.7Ø	21[illegible]
	9	178.25	191.41	191.9Ø	184.ØØ	19[illegible]
	1Ø	2Ø7.24	2Ø7.Ø9	2Ø7.14	2Ø7.24	2Ø7.14
	11	162.15	161.75	162.15	162.15	162.15
	12	2Ø1.37	2Ø1.37	2Ø1.37	2ØØ.97	2Ø1.77
	13	185.99	191.59	216.23	24Ø.67	186.21
GROUP MEAN		194.18	195.74	198.ØØ	198.84	195.96
S.D.		15.867	14.926	16.62Ø	19.639	15.Ø85

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	16164	64	
BETWEEN	182.438	4	45.6Ø94
WITHIN	15981.6	6Ø	266.36

F-RATIO = .171232

DEGREES OF FREEDOM = 4 & 6Ø

3. BASELINE

MEAN 196.54 mnhrs

S.D. 15.891 mnhrs

95% Conf Limits 192.68 $\leq X \leq$ 2ØØ.41

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-Ø.4Ø	-Ø.13	Ø.65	1.42	-Ø.2Ø
INTECEPT	196.96	196.64	193.47	188.89	197.35
r^2	Ø.Ø1	Ø.ØØ1	Ø.Ø3	Ø.Ø8	Ø.ØØ3
ts	-Ø.325	-Ø.111	Ø.543	Ø.974	-Ø.172

FACILITIES MAINTENANCE MANHOURS

1.

SEED		129	157	177	199	999
WEEK	1	487.27	488.73	488.53	499.00	487.05
	2	511.02	514.97	513.01	512.23	514.07
	3	499.82	501.92	498.85	502.38	502.78
	4	525.16	535.68	513.66	519.20	513.02
	5	505.89	505.42	506.39	506.32	505.18
	6	495.64	495.47	495.52	495.12	495.47
	7	507.52	507.92	510.14	509.61	509.61
	8	509.28	506.13	508.25	508.54	509.14
	9	481.35	470.51	475.90	490.52	490.25
	10	500.76	500.28	504.60	501.01	500.83
	11	462.71	468.04	464.08	467.22	468.20
	12	494.46	494.33	494.23	494.96	494.60
	13	514.34	518.16	519.50	504.90	529.92
GROUP MEAN		499.63	500.58	499.44	500.16	501.63
S.D.		16.045	18.327	15.887	13.146	15.213

SUMMARY TABLE
ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	15028.7	64	
BETWEEN	29	4	7.25
WITHIN	14999.7	60	249.995

F-RATIO = .0290006

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 500.24 mnhrs

S.D. 15.214 mnhrs

95% Conf Limits $495.54 \le \overline{X} \le 503.94$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-0.98	-1.25	-0.67	-1.14	-0.18
INTERCEPT	506.46	509.33	504.15	507.90	502.90
r^2	0.05	0.07	0.03	0.11	0.002
ts	-0.808	-0.914	-0.556	-1.179	-0.159

HOURS-TOTAL SHIP READINESS SCORE C-1

1.

SEED		129	157	177	199	999
WEEK	1	128.96	154.82	160.60	148.23	120.94
	2	127.54	134.03	131.37	78.42	111.89
	3	148.00	149.57	97.83	143.91	149.55
	4	64.49	114.26	160.89	154.50	168.00
	5	161.76	123.76	141.45	152.21	164.75
	6	29.90	154.40	144.21	168.00	166.65
	7	136.14	54.55	117.32	165.14	125.69
	8	168.00	33.90	151.66	119.40	75.67
	9	98.97	146.85	133.37	163.01	91.63
	10	165.67	138.85	116.73	85.62	154.57
	11	166.44	94.26	119.54	94.02	137.00
	12	162.75	144.58	167.15	152.15	168.00
	13	151.71	53.04	52.39	152.34	132.41
GROUP MEAN		131.56	115.14	130.35	136.69	135.90
S.D.		43.01	42.554	31.07	31.402	30.109

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	78821.6	64	
BETWEEN	5337.63	4	1334.41
WITHIN	73484	60	1224.73

F-RATIO = 1.08955

DEGREES OF FREEDOM = 4 & 60

3. BASELINE · MEAN 131.47 mnhrs
S.D. 33.545
95% Conf Limits 123.31 $\le X \le$ 139.62

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	3.31	-4.28	-2.88	-0.22	0.12
INTERCEPT	116.09	145.13	150.53	138.22	135.07
r^2					
ts	1.551	-1.413	-1.285	-0.090	0.059

HOURS-TOTAL SHIP READINESS SCORE C-2

1.

SEED		129	157	177	199	999
WEEK	1	39.Ø6	13.19	1.3Ø	12.57	47.97
	2	3.6Ø	28.73	27.Ø2	89.58	6.12
	3	2.89	13.Ø1	2.23	24.11	13.45
	4	1.94	41.92	2.45	9.8Ø	Ø
	5	1.35	17.65	2Ø.34	12.Ø2	3.25
	6	Ø	13.6Ø	22.91	Ø	Ø
	7	7.65	97.22	27.58	Ø	42.32
	8	Ø	24.58	13.51	13.89	53.26
	9	Ø	18.Ø4	24.1Ø	Ø	21.41
	10	Ø	26.36	51.27	.29	3.Ø4
	11	1.56	21.38	1.65	10.57	31.ØØ
	12	5.25	2.48	.85	15.86	Ø
	13	9.5Ø	21.54	66.35	7.95	35.59
GROUP MEAN		5.6	26.13	2Ø.89	15.13	2Ø.5Ø
S.D.		1Ø.5Ø3	23.362	2Ø.854	23.54Ø	2Ø.455

SUMMARY TABLE
ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	279Ø9.3	64	
BETWEEN	3147.49	4	786.873
WITHIN	24761.8	6Ø	412.697

F-RATIO = 1.9Ø666

DEGREES OF FREEDOM = 4 & 6Ø

3. BASELINE MEAN 17.65 mnhrs

S.D. 2Ø.88 mnhrs

95% Conf Limits $12.57 \leq \overline{X} \leq 22.73$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-1.Ø1	-Ø.45	2.21	-2.69	Ø.3Ø
INTERCEPT	12.64	29.31	5.44	33.94	18.41
r^2	Ø.14	Ø.Ø1	Ø.17	Ø.2Ø	.ØØ3
ts	-1.322	-Ø.252	1.52Ø	-1.646	Ø.139

HOURS-TOTAL SHIP READINESS SCORE C-3

1.

SEED		129	157	177	199	999
WEEK	1	0.00	0.00	6.11	7.22	0
	2	36.86	5.24	9.61	0	50.00
	3	17.11	0.00	67.94	0	0
	4	91.78	11.83	4.66	3.70	0
	5	4.89	26.63	6.21	3.76	0
	6	38.09	0.00	0.89	0	1.35
	7	19.29	15.96	.92	2.68	0
	8	0.00	0.00	2.10	34.70	34.07
	9	69.03	3.11	10.53	4.99	54.96
	10	2.33	2.78	0.00	82.08	10.40
	11	0.00	52.36	45.49	63.42	0
	12	0.00	20.93	0.00	0	0
	13	6.79	93.43	49.26	7.72	0
GROUP MEAN		22.01	19.09	15.67	17.29	11.70
S.D.		29.494	26.728	22.778	26.387	20.439

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	39376.6	1	
BETWEEN	771.101	4	192.775
WITHIN	38605.5	60	643.425

F-RATIO = .299608 < 2.53

DEGREES OF FREEDOM 4 & 60

3. BASELINE MEAN 16.66 mnhrs

S.D. 25.279 mnhrs

95% Conf Limits $10.58 \leq \overline{X} \leq 22.75$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-2.14	4.25	.64	2.91	-.42
INTERCEPT	37.02	-11.91	11.17	-4.17	14.53
r^2	0.08	0.37	0.01	0.18	0.01
ts	-0.979	2.541	0.366	1.533	-.265

HOURS-TOTAL SHIP READINESS SCORE C-4

1.

SEED / WEEK	129	157	177	199	999
1	0.00	0.00	0.00	0	0
2	0.00	0.00	0.00	0	0
3	0.00	5.42	0.00	0	0
4	9.79	0.00	0.00	0	0
5	0.00	0.00	0.00	0	0
6	0.00	0.00	0.00	0	0
7	4.92	0.28	12.18	.19	0
8	0.00	109.53	0.72	0	0
9	0.00	0.00	0.00	0	0
10	0.00	0.00	0.00	0	0
11	0.00	0.00	1.33	0	0
12	0.00	0.00	0.00	0	0
13	0.00	0.00	0.00	0	0
GROUP MEAN	1.13	8.86	1.09	0.01	0
S.D.	2.936	30.283	3.355	0.053	0

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	11976.4	1	
BETWEEN	732.994	4	183.248
WITHIN	11243.4	60	187.39

F-RATIO = .977899< 2.53

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 2.22 mnhrs

S.D. 13.679 mnhrs

95% Conf Limits $-1.10 \leq \overline{X} \leq 5.55$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-0.16	0.48	0.03	0.00	-.02
INTERCEPT	2.26	5.49	0.86	0.01	0.27
r^2	0.05	0.003	0.001	0.01	0.15
ts	-0.727	0.226	0.128	0.00	-1.382

HOURS-PROPULSION SUBSYSTEM READINESS SCORE C-1

1.

SEED		129	157	177	199	999
WEEK	1	128.96	168.02	160.60	166.70	135.71
	2	131.15	137.88	158.39	168.00	118.28
	3	150.73	159.95	100.06	154.68	163.08
	4	66.44	152.33	165.55	154.50	168.00
	5	161.76	139.90	143.53	159.90	164.75
	6	129.90	168.00	167.11	168.00	168.00
	7	138.36	102.50	121.68	165.14	125.69
	8	168.00	33.90	155.75	123.57	80.16
	9	98.97	168.00	152.62	163.01	121.89
	10	165.67	160.46	163.97	98.33	154.57
	11	168.00	161.17	120.38	104.67	153.53
	12	168.00	147.07	168.00	168.00	168.00
	13	161.21	53.02	59.14	160.29	168.00
GROUP MEAN		141.32	134.79	141.29	150.37	145.36
S.D.		30.857	44.441	32.610	24.692	27.244

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	65829.8	1	
BETWEEN	1719.78	4	429.945
WITHIN	64110	60	1068.5

F-RATIO = .402382 < 2.53

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 142.62 mnhrs

S.D. 32.072 mnhrs

95% Conf Limits $134.83 \leq \overline{X} \leq 150.42$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	3.61	-3.81	-2.62	-2.45	1.05
INTERCEPT	116.05	161.43	159.65	167.49	138.04
r^2	0.21	0.11	0.10	0.15	0.02
ts	1.698	-1.173	-1.094	-1.387	0.501

HOURS-PROPULSION READINESS SCORE C-2

1.

SEED		129	157	177	199	999
WEEK	1	39.06	0.00	1.30	0	32.29
	2	0.00	24.88	0.00	0	6.12
	3	0.17	8.05	0.00	13.33	4.93
	4	0.00	3.84	2.45	4.80	0
	5	1.35	1.47	18.26	4.34	3.25
	6	0.00	0.00	0.00	0	0
	7	5.43	65.21	33.23	0	42.32
	8	0.00	24.58	10.14	9.72	59.72
	9	0.00	0.00	13.57	0	0
	10	0.00	7.39	4.03	0	3.04
	11	0.00	0.00	0.81	0	14.47
	12	0.00	0.00	0.00	0	0
	13	0.00	21.55	63.09	0	0
GROUP MEAN		3.54	12.07	11.30	2.86	12.78
S.D.		10.779	18.666	18.417	4.836	19.510

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	15733	1	
BETWEEN	1239.38	4	309.846
WITHIN	14493.6	60	241.559

F-RATIO = 1.28269 < 2.53

DEGREES OF FREEDOM = 4 & 60

3. BASELINE MEAN 8.51 mnhrs

S.D. 15.678 mnhrs

95% Conf Limits $4.70 \leq \bar{Y} \leq 12.32$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-1.31	0.03	2.04	-0.39	-0.63
INTERCEPT	12.68	11.88	-2.84	5.66	17.54
r^2	.22	0.00	0.19	0.05	0.02
ts	-1.766	0.019	1.597	-0.793	-0.45

HOURS PROPULSION SUBSYSTEM READINESS SCORE C-3

1.

SEED / WEEK	129	157	177	199	999
1	Ø	Ø	6.11	1.32	Ø
2	36.86	5.24	9.61	Ø	43.61
3	17.11	Ø	67.94	Ø	Ø
4	91.78	11.83	Ø	3.7Ø	Ø
5	4.89	26.63	6.21	3.76	Ø
6	38.09	Ø	.89	Ø	Ø
7	19.29	Ø	.92	2.68	Ø
8	Ø	Ø	2.1Ø	34.7Ø	28.11
9	69.Ø3	Ø	1.82	4.99	46.11
10	2.33	.15	Ø	69.67	1Ø.4Ø
11	Ø	6.84	46.82	63.33	Ø
12	Ø	2Ø.94	Ø	Ø	Ø
13	6.79	93.42	45.77	7.72	Ø
GROUP MEAN	22.Ø1	12.7Ø	14.48	14.76	9.86
S.D.	29.494	25.81Ø	23.Ø15	24.762	17.468

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS
TOTAL	3686Ø.4	64	
BETWEEN	1Ø51.94	4	262.986
WITHIN	358Ø8.4	6Ø	596.8Ø7

F-RATIO = .44Ø654

DEGREES OF FREEDOM 4 & 6Ø

3. BASELINE MEAN 14.76 mnhrs
S.D. 23.999 mnhrs
95% Conf Limits 8.92 $\leq X \leq$ 2Ø.6Ø

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-2.14	3.18	Ø.54	2.89	-Ø.37
INTERCEPT	37.Ø2	-9.54	1Ø.71	-5.5Ø	12.42
r^2					
ts	-Ø.979	1.811	Ø.3Ø3	1.696	-Ø.271

HOURS-PROPULSION SUBSYSTEM READINESS SCORE C-4

1.

SEED	129	157	177	199	999
WEEK 1	Ø	Ø	Ø	Ø	Ø
2	Ø	Ø	Ø	Ø	Ø
3	Ø	Ø	Ø	Ø	Ø
4	9.79	Ø	Ø	Ø	Ø
5	Ø	Ø	Ø	Ø	Ø
6	Ø	Ø	Ø	Ø	Ø
7	4.92	.28	12.18	.19	Ø
8	Ø	109.53	Ø	Ø	Ø
9	Ø	Ø	Ø	Ø	Ø
10	Ø	Ø	Ø	Ø	Ø
11	Ø	Ø	Ø	Ø	Ø
12	Ø	Ø	Ø	Ø	Ø
13	Ø	Ø	Ø	Ø	Ø
GROUP MEAN	1.13	8.45	Ø.94	Ø.Ø1	Ø.ØØ
S.D.	2.936	3Ø.372	3.378	0.053	Ø.ØØ

SUMMARY TABLE

ANALYSIS OF VARIANCE

2.

SOURCE	SS	DF	MS	F-RATIO
TOTAL	11977	64		.88507
BETWEEN	667.327	4	166.832	DEGREES OF FREEDOM
WITHIN	113Ø9.7	6Ø	188.495	4 & 60

3. BASELINE MEAN 2.11 mnhrs

S.D. 13.68Ø mnhrs

95% Conf Limits $-1.22 \leq \overline{X} \leq 5.43$

4. TREND ANALYSIS

SEED	129	157	177	199	999
SLOPE	-Ø.16	Ø.6Ø	Ø.ØØ	Ø.ØØ	-Ø.Ø3
INTERCEPT	2.26	4.23	Ø.94	Ø.Ø1	Ø.27
r^2	Ø.Ø5	Ø.Ø1	Ø.ØØ	Ø.Ø1	Ø.15
ts	-Ø.727	Ø.257	Ø.ØØ	Ø.ØØ	Ø.ØØ

Sensitivity Analysis

Model sensitivity can be defined as the degree to which the dependent variable of interest is responsive to changes in the value of the independent variable of interest. If the output variable is not sensitive to the value of the input variable, then either the presumed relationship does not in fact pertain or the relationship is masked by other effects in the model. If the model is valid, then the lack of sensitivity, mirroring the real world, is not a model problem but, rather, a problem in the choice of application. A valid model, then, is useful in those areas in which it is sensitive.

The sensitivity analysis was limited to the smaller data base used in the baseline stability tests. The main propulsion (MP) division, which includes both main propulsion and auxiliary systems in the DD 963, is a maintenance intensive division that should show the expected response to maintenance parameter changes.

The sensitivity analysis consisted of the following steps:

1. Select Dependent Variables. The output variables examined for responsiveness to changes in input variables which were the same as those selected for study in the baseline stability tests, are listed below:

a. Watch hours, individual and total.
b. Divisional training hours.
c. Evolution hours.
d. PM hours.
e. CM hours.
f. Ship's work-hours.
g. Total hours.

2. Select Independent Variables. The input variables selected for variation in the model sensitivity analysis were:

a. Mean time between failures (MTBF).
b. Mean time in function repair (MTFR).
c. Mean time in function preventive maintenance (MTFPM).
d. Probability of deferrals for assistance.
e. Probability of deferrals for parts.
f. Mean time of deferrals for assistance.
g. Mean time of deferrals for parts.

3. Model Runs. To test model sensitivity to changes in the input variables, a single input variable was changed in each model run. The change was accomplished using the parametric variation ratio feature of the SHIP-II model. Parametric variation ratios can be used to uniformly alter values of selected variables by a selected percentage.

Input variable levels were changed in steps and the results of each model run compared with the previous baseline stability run using the same random number seed. If there were significant differences between the sensitivity analysis and baseline stability runs, further runs were made at a decreased level. This process continued until there was no significant difference between the outputs of the sensitivity analysis and the baseline stability runs.

The steps chosen resulted in 90-, 70-, 50-, and 10-percent changes in the input variable. Model run cost considerations limited this analysis to these levels.

4. Analysis Method. The mean values of the dependent variables from the sensitivity and baseline runs were compared using the t-test for the difference between two means. The hypothesis to be tested is that two populations have the same mean when the population standard deviation, σ, is not known. To test the hypothesis that a certain change in the input variable results in a statistically significant change in the outputs, the results of the sensitivity analysis run were compared with the baseline stability run.

a. H1: $\mu_1 = \mu_2$, given $\sigma_1 = \sigma_2 = \sigma$, with the value of σ unknown.

b. Choose $\alpha = .05$.

c. For a statistic to test this hypothesis use

$$t_s = \frac{\bar{X}_1 - \bar{X}_2}{S_p \sqrt{(1/N_1) + (1/N_2)}} ,$$

where S_p^2 is the pooled mean-square estimate of σ given by

$$S_p^2 = \frac{\sum X_{1_j}^2 - ((\sum X_{1_j})^2/N_1) + \sum X_{2_j}^2 - ((\sum X_{2_j})^2/N_2)}{N_1 + N_2 - 2} ,$$

where $\sum X_{1_j}^2$ = sum of squares in the baseline stability run,

$\sum X_{2_j}^2$ = sum of squares in the sensitivity analysis run,

$\sum X_{1_j}$ = sum of observations in the baseline stability run, and

$\sum X_{2_j}$ = sum of observations in the sensitivity analysis run.

d. If both populations have normal distributions with the same mean and the same variance, then this statistic has the $t_{(N_1 + N_2 - 2)}$ distribution.

e. The critical region consists of values of $t_s < t_{c_1}$ or $t_s > t_{c_2}$ with a one-tail test,

where $t_{c_1} = t_{\frac{1}{2}\alpha\,(N_1 + N_2 - 2)} = 1.796$

$t_{c_2} = t_{1 - \frac{1}{2}\alpha\,(N_1 + N_2 - 2)}$

f. Compute t_s.

g. Reject or accept the hypothesis.

The statistically significant changes resulting from this analysis are provided below:

a. Mean time between failures.

Corrective Maintenance Man-hours

	Baseline	90% Decrease	70% Decrease	50% Decrease
Mean	61.91	450.41	220.64	107.217
Std Deviation	37.29	119.75	57.62	49.537
t_s		-10.730	-8.012	-2.531
Total Maintenance Man-hours				
Mean	2716.46	3048.06		
Std Deviation	319.36	302.17		
t_s		-2.613		

b. Mean time in function repair.

Corrective Maintenance Man-hours

	Baseline	90% Increase	50% Increase	30% Increase
Mean	61.91	128.78	118.518	124.148
Std Deviation	37.29	58.17	68.074	70.182
t_s		-3.353	-2.526	-2.713
Division Training Man-hours				
Mean	23.23		18.730	
Std Deviation	5.98		2.610	
t_s			2.389	

c. Mean time in function planned maintenance.

Preventive Maintenance Man-hours

	Baseline	90% Increase	50% Increase
Mean	203.17	297.27	255.134
Std Deviation	50.72	65.26	60.838
t_s		-3.9439	-2.2726
Division Training Man-hours			
Mean	23.23	19.850	
Std Deviation	5.98	1.443	
t_s		-1.90334	

APPENDIX C

SMD/NMP MANNING DIFFERENCES

Table C-1

SMD/NMP Manning Differences by Navy Enlisted Classification (NEC) Code

NEC Code	SMD Primary	SMD Secondary	NMP Primary	NMP Secondary
312	12	3	12	--
316	--	--	--	1
318	1	--	1	--
321	3	--	--	--
341	1	--	1	--
437	4	--	1	--
445	1	1	1	--
447	2	--	2	--
457	4	--	6	--
474	2	--	3	--
877	8	--	8	--
891	8	--	4	--
993	2	--	2	--
1111	1	--	1	--
1125	7	--	4	--
1148	3	--	3	--
1422	--	--	--	1
1423	--	--	1	1
1426	--	--	1	--
1431	--	--	1	--
1436	--	--	1	--
1438	--	--	1	--
1453	--	--	1	1
1454	--	--	--	2
1473	--	--	1	--
1479	--	--	1	--
1504	--	--	--	2
1516	--	--	2	--
1572	--	--	1	--
1615	1	--	1	--
1623	1	--	1	--
1668	--	--	--	1
1672	2	1	3	--
1682	2	--	1	--
1731	1	--	--	--
1733	2	--	--	--
1763	--	--	1	--
1764	--	--	2	--
2304	3	--	3	--
2313	1	--	1	--
2314	--	--	1	--
2342	--	--	1	--
2346	3	--	2	--
2616	1	--	1	--
2816	1	--	1	--
3112	1	--	1	--
3122	1	--	1	--
3155	2	--	1	--
3529	2	--	2	--
3533	2	--	1	--
4105	2	--	4	--
4111	13	--	12	--
4112	6	--	5	2
4115	2	--	2	--
4291	2	--	--	--
4398	2	--	3	--
4613	--	--	1	--
4626	1	--	--	--
4715	1	--	3	--
4724	1	--	1	--
4745	--	--	--	2
4775	--	--	--	1
4776	1	--	--	--
4931	--	--	1	--
4951	--	--	1	--
4952	--	--	1	--
4954	3	--	--	--
8425	--	1	1	--
9512	--	1	--	1
9535	--	--	--	8
9555	--	--	--	4

Table C-2

SMD/NMP Manning Differences by Pay Grade and Rating

Item	SMD	NMP
Pay Grade		
E-9	1	--
E-8	3	3
E-7	20	15
E-6	36	25
E-5	49	54
E-4	88	59
E-3	102	90
Total	299	246
Rating		
BM	14	6
DK	2	2
DS	6	6
EM	7	6
EN	12	9
ET	11	11
EN	6	3
FTG	8	6
FTM	8	8
GMG	8	8
GMM	3	2
TMT	8	4
GS	1	1
GSE	8	7
GSM	26	19
HM	2	2
HT	9	12
IC	5	5
MA	1	1
MR	1	1
MS	12	10
OS	22	14
PC	1	1
PN	3	2
QM	5	4
RM	13	14
SH	6	5
SK	5	5
SM	6	6
STG	17	20
TM	3	2
YN	5	4
FN	13	9
SN	42	31
Total	299	246

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8